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Playful learning with sound-augmented toys: comparing children with and without visual impairment

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Abstract
Sound-augmented toys producing factual knowledge were thought to encourage incidental, playful learning in children with visual impairments (VIs). A group of 15 children with VIs and 22 sighted controls played with a sound-augmented savannah landscape and listened to an informative story in a counterbalanced order. Children's knowledge about savannah animals was assessed at baseline and after each condition in order to quantitatively compare knowledge gains between conditions. Results indicated that children with VIs gained more knowledge than sighted controls from playing with the sound-augmented toy. Furthermore, offering both the augmented toy and the informative story led to higher knowledge gains than a single medium, especially in children with VIs. Sound-augmented toys could therefore be a useful addition to the current curriculum in special education for children with VIs.

KEYWORDS
augmented toys, children with visual impairments, factual knowledge learning, playful learning, science education

1 | INTRODUCTION

Nowadays, technology is often integrated in education in order to increase students' learning motivation or flow and to induce learning by "doing," for example by means of serious games, augmented reality or technology-enhanced learning environments (Squire, 2006; Squire, 2008; Kangas, 2010; Kirriemuir & McFarlane, 2004). Although direct instruction is often referred to as the most effective method to enhance learning (Chall, 2000; Hattie, 2008), a body of research also indicates that learning will also take place during self-directed activities that allow for interaction, experimentation, and collaboration (Jonassen, 2002; Kangas, 2010; Moreno & Mayer, 2007; Price, Rogers, Scaife, Stanton, & Neale, 2003; Sommerauer & Müller, 2014). Game-based learning has been found to increase student engagement and learning, both in typical learners as well as learners with disabilities (Giannakos, 2013; Junco & Cole-Avent, 2008; McMahon, Cihak, Wright, & Bell, 2016; Piki, Markou, & Vasiliou, 2016; Shin, Sutherland, Norris, & Soloway, 2012). Furthermore, augmented reality games on mobile devices (e.g., smart phones or tablets) enable students to learn outside the classroom, consequently expanding the range of interactive learning opportunities (Huang, Chen, & Chou, 2016; Rogers et al., 2004; Sommerauer & Müller, 2014; Yoon, Elinich, Wang, Steinmeier, & Tucker, 2012). However, children with visual impairments (VIs) are often challenged or unable to benefit from game-based contexts, as these mostly require children to have adequate visual abilities (Bieliková, Divéky, Jurnečka, Kajan, & Omelina, 2008). For students with VIs, tactile or audio experiences need to exceed visual information (Nees & Berry, 2013; Sahin & Yorek, 2009). Although several studies qualitatively examined instructional methods for children with VIs (Koenig & Holbrook, 2000; Kumar, Ramasamy, & Stefanich, 2001; Sahin & Yorek, 2009), studies examining how incidental, exploratory learning during meaningful activities could be encouraged in children with VIs are scarce (Jeon, Winton, Yim, Bruce, & Walker, 2012; Walker, Kim, & Pendse, 2007). Most studies that investigated the accommodation of effective learning in this population focused on braille reading, the magnification of learning materials, or synthetic speech (Hasselbring & Glaser, 2000). In the present study, it was explored whether sound-augmented toys can facilitate playful learning in children with VIs in special elementary education for the visually impaired and the blind.

Augmented environments (i.e., tangibles) and mobile games combine physical materials with technology, creating possibilities for increased object interaction by enriching objects or toys with audio, tactual, or visual features. These novel possibilities for object interaction allow children to relate newly discovered information to previous experiences or existing knowledge (Marshall, 2007). Several studies described that augmented toys and mobile games stimulated problem solving, cooperation, and exploration in typically developing children (Facer et al., 2004; Hinske, Lampe, Price, Yuill, & Langheinrich, 2010; Huang et al., 2016; Yuill, Hinske, Williams, & Leith, 2014; Price et al., 2003; Spikol & Milrad, 2008). For example, in a study of Hinske and others (2010), 103 children aged between 6 and 10 played in dyads or triads with a sound-augmented medieval castle (i.e., the Augmented Knight's Castle), which was enriched with background music, verbal commentary of play figures, and educational content. Results indicated that incidental learning occurred when children used the Augmented Knight's Castle and that most children were able to reproduce the same information 2 months later (Hinske et al., 2010). Also, the extended possibilities for object interaction during play are thought to make augmented materials accessible to young children and children with disabilities (Lin et al., 2016; McMahon et al., 2016; Richard, Billaudeau, Richard, & Gaudin, 2007; Zuckerman, Profile, Zuckerman, Arida, & Resnick, 2005). For example, a similar augmented castle was also found to facilitate peer play in children with autism (Farr, Yuill, & Hinske, 2007) and to encourage object exploration and a focus on the playmate's actions in dyads of 4- to 12-year-old children with VIs (Verver, Vervloed, & Steenbergen, 2019a, 2019b).

In order to take the specific need for auditory information or haptics into account, multiple games have been designed specifically for users with VIs or in such a way that games with visual elements are accessible to users with VIs (Buzzi, Buzzi, Leporini, & Senette, 2015; Drossos, Zormpas, Giannakopoulos, & Floros, 2015; Sánchez, Saenz, & Garrido, 2010; Jeon et al., 2012; Lozano, Penichet, Leporini, & Fernando, 2018; Song, Karimi, & Kim, 2011; Stockman, Rajgor, Metatla, & Harrar, 2007; Wilkerson, Koenig, & Daniel, 2010). Related studies primarily focused on examining the usability of these games for people with VIs, and only a few studies investigated their potential for game-based learning. Sánchez and Elías (2007) showed that Audiolink, a multimedia-based audio tool, encouraged problem solving and engagement during science education in children with VIs. Also, Kabátová and others (2012) described the successful use of the so-called Bee-Bot, a toy that could memorize and produce 40 instructions and could be programmed to move across a grid mat as part of educational robotics for children with VIs in special education. However, both studies lacked a controlled experimental design, indicating the need for additional research that investigates the potential of motivating and informal learning environments to effectively encourage learning in children with VIs.

This study examined whether a sound-augmented savannah landscape encouraged school-aged children with VIs and a comparison group of sighted children to gain context specific knowledge, in this case, about savannah animals and their habitat. Biological knowledge as part of science education was offered as an exemplar of the use of augmented toys. The following research question was postulated: "How effective are augmented toys in facilitating factual knowledge learning in children with visual impairments and a comparison group of sighted children?" Both this playful learning context and a more passive educational setting (i.e., listening to an informative story) were offered to participants, in order to compare which context was more effective. Based on previous studies showing the benefits of augmented toys as learning environments (Facer et al., 2004; Hinske et al., 2010; Kangas, 2010; Lin et al., 2016), it was expected that children (both with a VI and sighted) would gain more knowledge from using the augmented toy than from the informative story. We expected this to be similar for both groups of children, because augmented toys were found to stimulate exploratory play in children with VIs and sighted children (Hinske et al., 2010; Verver, Vervloed, Steenbergen, 2019a, 2019b). Moreover, the combination of both learning contexts was hypothesized to lead to higher knowledge gains than participating in only one learning context because repeated exposure to factual knowledge leads to better retention (Hulstijn, 2011). In this case, augmented toys could be a useful addition to the current curriculum of children with VIs in special education in particular.

2 | METHOD

2.1 | Participants

Parents of 30 children with a VI as their primary disability were approached for consent for children's participation in the study. Parents received informed consent letters if their child (a) attended special education for the visually impaired and the blind, (b) was aged between 6 and 10 years old, (c) had an intelligence score >70, and (d) did not have hearing problems. Intelligence and hearing status were included because reduced intelligence and hearing could have influenced the possibilities children had to gain knowledge from auditory information. The final participant group consisted of 15 children (*M* age = 8.59 years, SD = 1.25; 47% girls) from three different special schools for the visually impaired. See Table 1 for details regarding participant characteristics. Although all children were supposed to participate in dyads to increase exposure to facts during play with the augmented toy, one child with a VI participated alone in this study due to the absence of the intended playmate.

In order to compare the findings for children with VIs with a group of sighted children, parents of 40 first graders from a single mainstream elementary school received informed consent letters for participation in this study. A total of 22 sighted children were allowed to participate (*M* age = 7.25, SD = 0.34; 50% girls) in dyads. It was decided not to match children based on their chronological age

TABLE 1 Participant characteristics of children with VIs (*N* = 15)

Participant	Dyad	Age (in years)	Gender	Visual acuity	Aetiology
1	A	8.41	F	0.09	Optic atrophy
2		8.48	F	0.08	Enophthalmus; iris coloboma
3	B	8.27	F	0.10	Albinism
4		8.41	F	0.07	Optic atrophy
5	C	9.11	M	0.00	Retinopathy of prematurity
6		8.08	M	0.32	Optic atrophy; cerebral visual impairment
7	D	880	F	0.10	Congenital nystagmus
8		9.68	F	0.00	Cerebral lymphoma; optic atrophy
9	E[a]	10.30	M	0.00	Congenital corneal opacity
10	F	7.18	M	0.13	Retinitis pigmentosa
11		6.49	F	0.10	Leber congenital amaurosis
12	G	6.16	M	0.40	Hypermetropia
13		10.02	M	0.00	Leber congenital amaurosis
14	H	9.48	M	0.01	Optic nerve hypoplasia
15		9.92	M	0.18	Congenital nystagmus

Note. Normal visual acuity is referred to as 1.00, suggesting a person with a visual acuity of 0.10 has 10% remaining sight (see World Health Organization, 2018).
[a]This child participated in the experiment on its own instead of in a dyad.

because children with VIs attending special education often have accompanying learning, social–emotional, or behavioural problems that could cause developmental delays (Inspectie van het Onderwijs, 2010). Instead, a small pilot study with 10 sighted first and second graders indicated that baseline knowledge about savannah animals of first graders was most comparable to that of participants with VIs.

2.2 | Materials

2.2.1 | Sound-augmented savannah landscape

A miniature savannah landscape with several different toy animals was offered to the participants (see Figure 1), because the topic "animals" was expected to be engaging for most school-aged children. The toy consisted of a large plywood base in which six radio frequency identification (RFID) readers were integrated, similar to the design of the Augmented Knight's Castle (for more detailed information, see Lampe & Hinske, 2007; Verver, Vervloed, Steenbergen, 2019a, 2019b). Twelve toy animals (3 lions, 3 zebras, 1 ostrich, 3 elephants and 2 crocodiles) were equipped with RFID tags that were registered when placed on one of the readers. As a result, sounds involving factual knowledge about animal characteristics (e.g., "African elephants are the worlds' largest and heaviest land-living animals. They weigh up to 6,000 kg and are very strong") and animal sounds (e.g., a lion's roar) were produced. See Appendix 1 for the factual knowledge that was offered. Sounds were specific for the animal (e.g., toy lions only produced sounds and facts about lions). Each animal would introduce itself upon the first registration of the RFID tag (e.g., "This is a zebra," after producing a zebra sound). In order to stimulate exploratory play, animals produced different sounds on each location on the board. Animal sounds and factual knowledge sounds were spread as evenly as possible across locations, without overloading children with facts. One of the locations represented a feeding place, with all animals producing facts about their diets on this location. In total, 15 sounds involving facts (three facts per animal type) and 14 different animal sounds were available. All sounds involving facts were recorded with the same female voice. The augmented toy produced a log file containing frequencies of the sounds that were produced during each play session1.

2.2.2 | Informative story

A 15-minute fantasy story was recorded containing the same factual knowledge as the augmented toy (see Appendix 1). The story was recorded with the same voice as the sounds involving facts produced by the augmented toy. It did not contain any sound effects. An independent elementary school teacher considered the story to be entertaining and age-appropriate for children aged 6 to 9.

2.2.3 | Questionnaire about savannah animals

In order to measure whether children gained knowledge about savannah animals from the augmented toy or the informative story, a structured questionnaire was designed. The questionnaire consisted of 15 different questions that measured the majority of the factual knowledge that would be presented to the participants (e.g., What do elephants and their young eat?). One of the questions (i.e., "How do zebras live?," answer: "in groups called harems") had to be excluded because many children stated they did not understand the question, and only one child gave the correct answer. A scoring form was developed with the help of two Masters students in Pedagogical and Educational Sciences and a research assistant. Children received 0.5, 1, or 1.5 points for every correct answer (depending on the specificity of the answer), with a total possible score of 42.5 points. See Appendix 2 for an overview of the questions, the correct answers, and scoring.

2.3 | Procedure

The study took place at the children's schools during two consecutive weeks. All children participated in a condition where they played with the augmented savannah landscape (augmented condition or AC) as well as in a condition where they listened to an informative story (story condition or SC). The order in which conditions were offered was counterbalanced across participants who were randomly assigned

FIGURE 1 The augmented savannah landscape [Colour figure can be viewed at wileyonlinelibrary.com]

either to start in the AC or in the SC. See Figure 2 for an overview of the study design for each group.

The first measurement week started with an individual baseline screening of the participants' knowledge about savannah animals. The researchers verbally asked questions using the structured questionnaire and wrote down the exact answers that were given. Additionally, verbal ability was assessed with the vocabulary subtest of the Wechsler Intelligence Scale for Children–III (Kort et al., 2005).

In the second measurement week (no more than 5 days after baseline screening), children participated in two experimental conditions. In the AC, the savannah landscape was placed on the floor, ready to play with as soon as a dyad entered the experimental room.

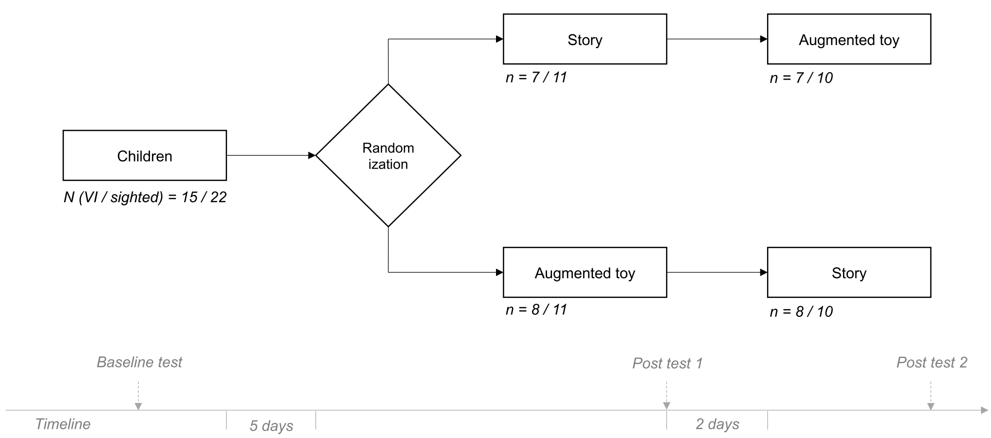

FIGURE 2 Diagram of the used study design. VI, visual impairment

Similar to the procedure of Hinske et al. (2010), children were told they could play with the toys as they liked, without giving a specific assignment. They were shown how to produce auditory feedback, and it was pointed out animals would give information about their diets at the feeding spot. Dyads had 15 min to play with the toys, and the play sessions were video-recorded. In the SC, both children were seated behind a laptop. They were instructed to quietly listen to a story about the savannah, which lasted for 15 min. Directly after the ending of each of the conditions, two researchers took the children separately apart for a post-test. The same questions were asked as during the baseline screening, only in a different order. Two days after the first condition took place, children participated in the second experimental condition and post-test. After all measurements ended, participants were asked the following questions: (a) "Which of the activities did you find more fun, playing with the augmented toy or listening to the story? Can you explain why?" and (b) "From which of these activities did you learn most? Can you explain why?"

Two different coders, one of whom was blind for the experimental conditions that children participated in and one who was involved in data collection, independently scored the answers of participants at baseline and post-test measures using the scoring form. Inter-rater agreement was excellent (ICC = 1.00) for both the scores of the children with VIs as well as the sighted children.

2.4 | Statistical analyses

All the analyses described below were performed for both the group of children with VIs and the sighted children. Per individual, the proportion of correct answers was calculated for each of the three screening measurements. Baseline knowledge was expected to vary within the group of children with VIs and also between groups of children with VIs and sighted children. Therefore, normalized gains were calculated, which takes into account that it is easier for learners with low baseline scores to gain knowledge than for learners with high baseline knowledge (Colt, Davoudi, Murgu, & Rohani, 2011; Hake, 1998). The following formula was used (based on Hake, 1998):

$$[(\text{Posttest} - \text{Pretest})/(1 - \text{Pretest})]$$

This resulted in three different relative gain scores: (a) Experiment 1 versus baseline (GS1), (b) Experiment 2 versus baseline (GS2), and (c) Experiment 2 versus Experiment 1 (GS2 vs. GS1). The independent variables were time (Experiment 1 or 2), condition (AC or SC), order (AC–SC or SC–AC), and group (VI or sighted). Gain scores vary from 0 (no gain) to 1 (maximum gain) if knowledge increases. If a decrease of knowledge occurs, gain scores vary from 0 to −1. Verbal ability (as a measure of cognitive performance) was assessed as a covariate. Finally, descriptive analyses were performed on frequency data regarding the use of the augmented toy, based on log data. For each participant, sound production was examined in relation to their performance on associated questions. We also examined for each child how sound repetition related to their performance on associated questions.

Statistical analyses were performed in SPSS Version 23. Despite the small sample size, assumptions regarding normality of standardized residuals, linearity, and homogeneity of variances were not violated for gain score variables in either of the participant groups. Because non-parametric tests lack statistical power (Whitley & Ball, 2002), we decided to use parametric tests to analyse these data. The following steps were taken for both participant groups separately. First, a one-sample t test was used to check whether children gained knowledge from the first condition compared with the baseline screening. Second, a one-way analysis of variance (ANOVA) was used to examine whether gain scores differed between conditions. Third, it was investigated whether participants gained more knowledge after both conditions compared with their score after one condition and if this differed as a function of order, using a repeated measures ANOVA. Both the gain scores as well as the baseline measures of the children with VIs were compared with that of the sighted children thereafter. Gain scores were compared between groups using multivariate and one-way ANOVA. Mann–Whitney U tests were used to compare the test scores at baseline measures between groups because these variables were non-normally distributed. Finally, descriptive analyses of log files of the augmented toy were performed to see how children used the toy and whether participants with VIs learned facts they heard during play. This was compared with knowledge gain after the story condition using one-way ANOVA.

3 | RESULTS

In the sighted group, two children completed only one experimental condition: One child missed the informative story, and one child missed the play session with the augmented toy. Furthermore, one participant with a VI and one sighted participant played with the toys individually instead of in a dyad. Because data reduction can have a significant influence on statistical power in a small sample (Enders, 2010), it was investigated whether the data of these participants could be kept in group mean analyses. Inspection of boxplots and standardized residuals did not reveal any outliers for either of the conditions of all dependent variables. As such, it was decided that all data remained part of the analyses. Table 2 presents means and standard deviations of the participants' scores on factual knowledge tests at baseline and after two experiments and the accompanying gain scores for both the VI group and the sighted group. Also, mean verbal ability scores for each group can be found in Table 2.

Pearson correlations showed that verbal ability was significantly correlated with knowledge gain in the children with VIs (GS1: $r = .65$, $p = .008$; GS2: $r = .62$, $p = .013$) and in the sighted children (GS1: $r = .79$, $p < .001$; GS2: $r = .53$, $p = .017$). More interestingly, for the children with VIs, the association between verbal ability and knowledge gain was present if children used the augmented toy (GS1 augmented toy: $r = .80$, $p = .017$; GS2 augmented toy: $r = .92$, $p = .003$) but not if they listened to the informative story (GS1 story: $r = -.02$, $p = .973$; GS2 story: $r = .28$, $p = .497$). This indicated that the higher the verbal

TABLE 2 Means and standard deviations of verbal ability scores

Verbal ability			Baseline	PT1	PT2	GS1	GS2	GS-2vs1
M (SD)			*M* (SD)	*M* (SD)	*M* (SD)	*M* (SD)	*M* (SD)	*M* (SD)
VI group	8.40 (4.67)	Total	0.09 (0.08)	0.25 (0.13)	0.36 (0.21)	0.18 (0.12)	0.31 (0.19)	0.16 (0.21)
		Start AC	0.11 (0.10)	0.28 (0.15)	0.45 (0.22)	0.21 (0.15)	0.38 (0.20)	0.12 (0.15)
		Start SC	0.06 (0.04)	0.21 (0.11)	0.26 (0.16)	0.14 (0.07)	0.22 (0.16)	0.20 (0.27)
Sighted group	9.73 (1.52)	Total	0.16 (0.08)	0.26 (0.12)	0.30 (0.14)[a]	0.12 (0.11)	0.18 (0.13)†	0.05 (0.13)[a]
		Start AC	0.17 (0.09)	0.23 (0.08)	0.32 (0.14)	0.07 (0.09)	0.20 (0.15)	0.14 (0.12)
		Start SC	0.15 (0.08)	0.28 (0.15)	0.27(0.14)	0.16 (0.12)	0.15 (0.10)	−0.03 (0.09)

Note. The proportion correct answers on factual knowledge tests at baseline and post-tests and relative gain scores for children with visual impairments (VI group; $N = 15$) and sighted children ($N = 22$). Verbal ability norm scores range from 1 to 19 (with scores of 8–12 representing average scores in Dutch norm population).
Abbreviations: *M*, mean; SD, standard deviation; PT1, post-test after first experiment; PT2, post-test after second experiment; GS1, relative gain score of PT1 versus baseline; GS2, relative gain score of PT2 versus baseline; GS-2vs1, relative gain score of PT2 versus PT1; Total, data of total group; Start AC, group that first used the augmented toy and listened to an informative story thereafter; Start SC, group that first listened to the informative story and used the augmented toy thereafter.
[a]$n = 20$

ability, the greater the learning gain, but only for the augmented condition. Although this did not lead to a violation of the assumption of homogeneity of regression slopes, correcting dependent variable means for verbal ability scores did cause heterogeneity of variances. Together with the small sample size ($N < 30$), this reduced the reliability of statistical results (Huitema, 2011), leading to the decision not to use verbal ability as a covariate to correct the results.

3.1 | Knowledge gain in the children with VIs

A one-sample *t* test showed that knowledge about savannah animals after the first condition (i.e., GS1) was significantly greater than at baseline (*M* difference = 0.18, $t\ (14) = 5.61$, $p < .001$, $r = .83$). A one-wayANOVA with condition as within-subjects factor revealed no significant difference between conditions for GS1 ($F(1, 14)= 1.59$, $p = .229$), suggesting that knowledge gain did not differ significantly between participants who used the augmented toy and those who listened to the informative story (see Figure 3). In addition, neither GS2 (i.e., gained knowledge after two conditions compared with baseline) nor GS-2vs1 (i.e., gained knowledge after condition 2 vs. 1) differed significantly between conditions (GS2: $F(1, 14)= 2.93$, $p = .110$; GS-2vs1: $F(1, 14) = 0.50$, $p = .505$). This suggests that total knowledge after two conditions did not differ as a function of the order in which the conditions were offered to the participants. In order to examine whether children gained more knowledge compared with baseline from participating in both conditions than in one condition, a repeated measures ANOVA was performed with time as within-subjects factor and order as between-subjects factor. Results indicated a significant main effect of time ($F(1, 14) = 7.05$, $p = .20$, $\omega^2 = .11$), a medium effect (Kirk, 1996), suggesting that GS2 was

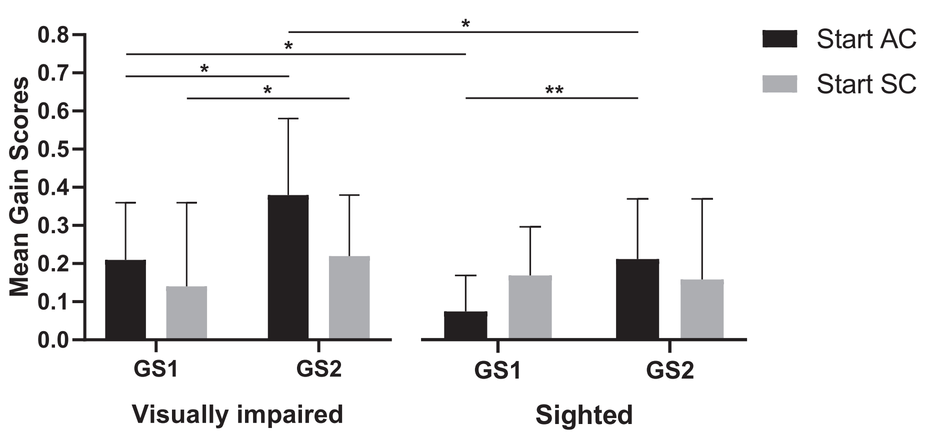

FIGURE 3 Mean knowledge gains after using the augmented toy and listening to the informative story in children with visual impairments and sighted children. *$p < .05$, ** $p < .01$; GS1 = relative knowledge gain after first experimental condition versus baseline; GS2 = relative knowledge gain after second experimental condition versus baseline; Start AC (black bars) = children who first used the augmented toy (GS1) and listened to an informative story thereafter (GS2); Start SC (grey bars) = children who first listened to the informative story (GS1) and used the augmented toy thereafter (GS2)

significantly larger than GS1. A trend towards a significant main effect of order (F(1, 13) = 3.63, p = .079) suggested that the difference between knowledge gains after one or both conditions took place was larger for children who first used the augmented toy and listened to the story thereafter than vice versa. The interaction effect order $\times$ time (F(1, 14) = 0.70, p = .417) was not significant.

3.2 | Knowledge gain in the sighted children

Just as in the VI group, a one-sample t test showed that GS1 was significantly larger than 0 (M difference = 0.12, t(21) = 4.79, p < .001, r = .72). Participants gained knowledge from the first exposure to either the augmented toy or the story. Results from a one-way ANOVA revealed that knowledge did not differ significantly between the augmented condition and the story condition (GS1: F(1, 21) = 3.90, p = .062). Neither did total knowledge after two exposures differ as a function of order (GS2: F(1, 19) = 0.96, p = .340). A significant difference between conditions was found for GS-2vs1 (F(1, 19) = 11.50, p = .003, ω^2 = .36, a large effect), indicating that gain scores were higher after the second than the first condition for children that first used the augmented toy. A one-way repeated measures ANOVA was used to further investigate differences between GS1 and GS2. Results revealed a significant interaction effect of time $\times$ order (F(1, 18) = 11.30, p = .003, ω^2 = .07, a medium effect). Compared with baseline, total knowledge after two conditions was higher than knowledge after one condition only for the participants that started in the AC (see Figure 3). Participants who first heard the story did not gain additional knowledge from using the augmented toy thereafter (F(1, 9) = 0.67, p = .436), whereas participants who first used the augmented toy gained additional knowledge from listening to the story thereafter (F(1, 9) = 11.76, p = .008, r = .75, a large effect).

3.3 | Comparison between participants with VIs and sighted participants

First, it was examined whether mean animal knowledge at baseline differed between participant groups. A Mann–Whitney U test showed that baseline scores of children with VIs (Mdn = 2.00) were significantly lower than those of sighted participants (Mdn = 6.75; U = 73.50, p = .004, r = −.47). As can be seen from Table 2, the proportion correct answers at baseline for children with VIs and sighted children were 0.09 and 0.16 respectively, implying that there still was enough room for both participant groups to gain knowledge from the experimental conditions. Results from a one-way ANOVA revealed that compared with baseline, participants with VIs gained more knowledge than sighted children after using the augmented toy (GS1: F(1, 18) = 6.59, p = .020, ω^2 = .23), whereas knowledge gain did not differ between groups after listening to the story (GS1: F(1, 17) = .273, p = .608). Total knowledge after two conditions was also higher for children with VIs than for sighted children, but this was only true for those who first played with the augmented toy and listened to the story thereafter (GS2: F(1, 18) = 4.94, p = .041, ω^2 = .18; see Figure 3). Total knowledge gain of children that started in the SC did not differ between participant groups (GS2: F(1, 16) = 1.47, p = .244). Finally, results of the ANOVA indicated that participants with VIs gained more additional knowledge (M = 0.19, SD = 0.27) from playing with the augmented toy after listening to the informative story than the sighted participants (M = 0.03, SD = 0.09; F(1, 16) = 6.06, p = .026, ω^2 = .23, a large effect).

3.4 | Use of the augmented toy and the effect on knowledge gain

In order to examine how participants used the augmented toys and how this related to knowledge gain, log file data were investigated containing frequencies of sound production in the AC. On average, children with VIs heard 45.8% of the 15 different sounds presenting factual knowledge. They elicited an average of 35.8 sounds, of which 39.3% were factual statements. As for the sighted children, they heard 44.2% of the 15 different facts. They produced 29.6 sounds on average, of which 41.8% were factual knowledge sounds. This suggests that both groups mainly heard animal sounds and only half of the available facts while using the augmented toy.

As participants produced fewer than half of the available sounds containing factual knowledge, it would be difficult for them to reach the total possible factual knowledge score of 42.5 in the AC. We therefore examined the relation between the factual information heard and the performance on associated questions more closely and whether this was more or less effective than information offered in the story. For participants with VIs who first used the augmented toy (n = 8), the total factual knowledge score that could be reached was 21.88 on average (SD = 6.85) based on the sounds that were produced. When we related factual sounds that participants produced to the questions they answered correctly, it appeared that participants remembered 47.4% of the knowledge they heard while using the toy. Compared with knowledge at baseline, this corresponded to a mean relative gain of 0.40, which is significantly higher than the non-adjusted relative knowledge gain of 0.21 when participants' sound production was not taken into account (Z = −2.52, p = .012; see Table 2: GS1 Start AC). Participants with VIs who first heard the informative story showed a relative gain of.14 compared with baseline, which is significantly lower than knowledge gain in the AC (Welch's F (1, 8.29) = 9.69, p = .014; see Table 2: GS2 Start SC). Further analysis of the effect of repeating sounds on learning showed that participants had higher scores on the questions that related to sounds they repeatedly heard than on those questions related to sounds they heard once (Z = −2.207, p = .027).

3.5 | Qualitative information on participants' opinions

After children participated in both conditions, they were asked which of the conditions they found more fun and from which of the conditions they learned most (VI group: n = 15; sighted group: n = 19). All children with VIs and 84.2% of the sighted participants experienced the augmented toy as more fun than the informative story. One sighted girl said she liked both conditions equally. Children mentioned they enjoyed that animals were able to produce sounds, that they were playing and learning at the same time, and that listening to the informative story could be boring or that it lasted for too long. Of the children with VIs, 80% answered that they learned most from the augmented toy, against 36.8% of the sighted participants. Sighted children who favoured the informative story as learning context mentioned that it contained more factual knowledge than the augmented toy because they did not hear some of the facts while playing with the toys. It was also mentioned they forgot facts because they were playing. One of the children with VIs stated that the augmented toy would be more suitable as learning context for children who are really into playing with animals than for those who are not.

4 | DISCUSSION

This is the first study that examines the effectiveness of sound-augmented toys to enhance implicit playful learning in school-aged children with VIs and a sighted comparison group. Results revealed both sighted and VI participant groups had comparable knowledge gains from the playful learning context as from an informative story, even though participants only heard fewer than half of the available factual knowledge while playing. A closer examination of the extent to which children with VIs learned the facts they produced during play revealed they remembered almost half of the facts they had heard, which equalled a knowledge gain of 40% compared with baseline. This implied the playful learning context was actually more effective than the informative story after which children with VIs remembered 21% of the facts, which equalled a knowledge gain of 14% compared with baseline. In line with previous studies, these results indicate that the augmentation of objects can encourage exploration and playful implicit learning during meaningful activities (Jonassen & Hernandez-Serrano, 2002; Facer et al., 2004; Hinske et al., 2010; J. Sánchez & Elías, 2007; Kabátová, Jašková, Leck, & Laššáková, 2012; Kangas, 2010; Lozano et al., 2018; Price et al., 2003). Although children did not hear all the factual knowledge that was presented in the story when they played with the augmented toy, they did have the opportunity to repeatedly listen to facts they found interesting, which is known to be important for retention (Hulstijn, 2011). The results indeed indicated participants with VIs remembered more facts if they heard them repeatedly than if they heard the information once. As hypothesized, a combination of both learning contexts led to the highest knowledge gain in children with VIs. A tendency indicated that the order in which conditions were offered might affect learning because children who first used the sound-augmented toy appeared to learn more from the story thereafter than children who participated in the conditions in the opposite order. A similar effect was found to be significant in the sighted comparison group. However, in both groups, the total knowledge gains after both learning contexts took place did not differ as a function of order. Based on our findings, it can be concluded that sound-augmented toys have the potential to be a promising addition to the current curriculum of children with VIs in special education and that future research should further investigate whether playful learning contexts are more effective preceding or following instruction.

Even though it was hypothesized that both groups of children were equally likely to benefit from the augmented toy, our results indicated children with VIs learned more about savannah animals from the playful learning context than sighted children did. This was not a consequence of toy use or a ceiling effect, as both groups heard similar amounts of factual knowledge and remembered no more than 39% of the total knowledge offered (see Table 2). When participants with VIs played with the toys first and listened to the story thereafter, they also learned significantly more than sighted children who received knowledge in this same order. Furthermore, sighted participants who first listened to the story did not gain additional knowledge from playing with the augmented toy thereafter, whereas children with VIs did. This suggests that both a single opportunity to play with the augmented toy as well as the combination of the two learning contexts were more effective for children with VIs than for sighted children. One explanation is that audio is a strong attention-getter (Yuill et al., 2014) and probably the best (in the case of children with blindness) or the second best (in children with low vision) way to access information for children with VIs (Bishop, 2004). There are indications that individuals with VIs show superior auditory processing to sighted individuals, also in the context of a noisy room (Edmonds & Pring, 2006; Muchnik, Efrati, Nemeth, Malin, & Hildesheimer, 1991; Röder, Rösler, & Neville, 2000). The participants with VIs might have been better able to selectively focus their attention to the auditory stimuli than the sighted children, especially in the augmented condition that was presumably more demanding for selective attention than the informative story. Furthermore, children with VIs might benefit additionally from the repetition of knowledge in different sensory modalities, which could explain why the augmented toy (which offers visual, auditory, and tactile information) has greater impact on them than on the sighted comparison group. The investigation of potential benefits of multisensory stimulation on learning in children with VIs would be an interesting topic for further research. Finally, in the absence of vision, children with VIs often need more time and repetition to learn than sighted children do (Sahin & Yorek, 2009), which might explain why the combination of both learning contexts was more effective than only one medium, especially in the VI group.

4.1 | Limitations and future directions

Some limitations should be mentioned regarding the design of the augmented toy. First of all, due to the small sample size, especially in the case of children with VIs, we decided to keep children who used the sound-augmented toy individually instead of in a dyad in the analyses. The main reason for participation in dyads was to increase the exposure to factual information: two children were likely to elicit more factual knowledge sounds than a single participant, especially because children with VIs need a significant amount of time to explore novel objects before they understand how to use them (Roe & Webster, 2004). It was carefully checked whether the data of these individuals did not involve any outliers that might have had a strong influence on the results. The children that participated alone (one child from the VI group and one from the sighted group) did not elicit fewer factual knowledge sounds than the dyads, and their knowledge gains also did not differ from other participants. We therefore assumed that their data would not bias group mean analyses. Similarly, we decided to analyse the data of two children who participated in only one of both learning conditions because each child represented a different condition, and their data did not involve outliers. However, this implied that the subsequent analyses were performed on 20 instead of 22 children. We emphasize once again that the current study had an exploratory character and that the effectiveness of augmented toys as motivating learning environments warrants further investigation in studies with sufficiently large samples.

Second, both the groups of children heard fewer than half of the available facts when using the augmented toy, which could be viewed as a limitation of the playful learning condition. With this study's augmented toy, sounds were specific for each location and for each toy animal. This was expected to encourage participants to actively explore different locations, and factual knowledge and animal sounds were programmed as evenly as possible across the landscape. However, participants predominantly listened to animal sounds instead of factual knowledge. As we did not want to overload children with facts, approximately three different facts were available per location, which might have been too few. Also, other than the feeding spot, there were no meaningful locations that were easy to recognize and that provided location-specific knowledge, suggesting that children had to discover where to find different sounds without any clues. On the one hand, this could imply that factual knowledge sounds should have been easier to access in the current setup. For example, in the study of Hinske et al. (2010), most sounds were played randomly, meaning that a larger variety of sounds was available at different locations. On the other hand, the finding that children heard half of the available facts and elicited more animal sounds might actually reflect how children use a playful learning environment. Play was the central element of this setting, and animal sounds might have been more attractive to children than facts and more supportive of play. Participants were free to play and explore the savannah landscape without further instructions. Because playing itself is characterized by high engagement through which learning and exploration occurs implicitly (Kangas, 2010), this is likely an important effective element of the playful learning environment. When the focus shifts from play to learning, for example by (implicitly) encouraging children to continue exploring factual knowledge when they are playing, this could also reduce the effectiveness of the playful learning context. In addition, children might have been exposed to less facts in the playful learning context, but they remembered significantly more of the facts they did hear when their sound production was taken into account. It is emphasized that a combination between playful learning and instruction is likely to lead to the highest learning outcomes. Furthermore, as children in our study only had one short opportunity to play with the augmented toy and explore the available sounds, multiple sessions with the toy could give a better idea of the potential for audio augmentation and playful learning. Finally, future research is necessary to examine whether improving the accessibility of factual knowledge might foster learning, for example by playing sounds randomly or by designing more meaningful locations.

Furthermore, results showed a relationship between verbal ability and learning in the playful learning context, but not in the story condition. As the same knowledge was offered in both conditions, this seems to be a result of the learning context rather than the difficulty of the information that was offered. As was stated earlier, it is probably more challenging for children to concentrate their attention on verbal information during play (when learning occurs implicitly) than in a passive instruction context. However, verbal ability was assessed using only a single subtest of a standardized intelligence test, indicating that this relationship should be investigated more closely using more extensive measurement methods. Future research should focus on the possible effects of cognitive ability in general on the effectiveness of playful learning in children with VIs, as former research showed cognitive performance to predict learning outcomes (Alloway & Alloway, 2010). In addition, this pilot study focused on a specific area of science education for children with VIs. In order to be a valuable addition to the existing curriculum of special education, future studies should also investigate the usefulness of augmented toys in other domains than science education. For example, Hinske et al. (2010) showed typically developing children learned historical knowledge in a playful learning context with sound-augmented toys. Another important theoretical implication is to examine possibilities for encouraging collaborative learning in children with VIs. Even though the children in this study participated in dyads, our objective did not involve promoting collaboration between children. Our study mainly focused on information acquisition, whereas collaboration involves shared knowledge construction in an attempt to solve problems together (Harasim, 2017). Using sound augmented toys in triads of typically developing children certainly increases collaborative social play (Yuill et al., 2014) and recent work of Thieme, Morrison, Villar, Grayson, and Lindley (2017) reveals how game-based learning environments, in this case a programming game, could be designed to effectively facilitate collaboration between children with VIs. Future studies should investigate how sound-augmented learning environments could be designed to encourage collaborative learning between children with VIs and (sighted) classmates, possibly using a framework such as that by Yuill and Rogers (2012).

4.2 | Practical implications

An important advantage of sound-augmented toys is that children can use the toys by themselves and together with peers, without the need for adult assistance. This allows children with VIs to explore and interact with objects by themselves or together with peers. Teachers could preprogram relevant factual knowledge and check the log file after children used the toy to keep track of the factual knowledge they listened to. Another advantage of this learning context is that children primarily experienced it as fun. Participants mentioned that they enjoyed the fact that animals were able to produce sounds, that they were playing and learning at the same time, and that listening to the informative story could be boring or that it lasted for too long. This suggests that the playful context can be a motivating addition to formal educational methods. One of the children remarked that the augmented toy would be more suitable as learning context “for children who are really into playing with animals than for those who are not.” Technological possibilities for augmenting materials need to be developed further so they are adjustable to different materials and educational topics before they can be used adequately in special education.

5 | CONCLUSIONS

Results of the present study indicate that children with VIs can benefit from incidental playful learning with sound-augmented toys. Augmented toys offered children with VIs increased possibilities for object interaction by enhancing play materials with audio feedback. Participants with VIs who used the augmented toy learned comparable knowledge to participants who listened to an informative story, despite not hearing as many facts. Furthermore, participants with VIs learned more from the augmented toy than a sighted comparison group. Whereas sighted children learned more effectively from listening to the story only, children with VIs learned most when both the augmented toy and the story were offered to them. This underlines the usefulness of sound-augmented toys as additional learning tools in special education for children with VIs.

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CONFLICTS OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. The funding source had no involvement in the collection, analysis, and interpretation of data; in the writing of the report; or in the decision to submit the article for publication.

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APPENDIX 1A

Factual knowledge that was presented by the augmented toy as audio fragments and as informative part of the story.

Zebras

- Zebras are relatives of horses and donkeys, but they are the only members living on the African savannah. You can recognize zebras by the black and white stripes on their bodies.
- A baby zebra is called a foal, just like the baby of a horse. The foals can walk and run immediately after they are born. This is important because lions that live on the savannah are hunting zebras! So, the zebra foals must be able to run away quickly.
- Zebras love to eat tall grasses and leaves. They eat all day long. The young drink milk from their mother.

Ostriches

- Ostriches are the largest and heaviest birds in the world. Because they are so heavy, they cannot fly. Ostriches have long and strong legs, with which they can run very fast. They also lay the largest eggs of all birds.
- Ostriches have a long, bare neck. Their body is covered with large feathers. You can recognize the male from its black feathers. The female is slightly smaller and has brown feathers.
- Ostriches like to eat grass and fruit, but they also enjoy insects and lizards. The chicks eat the same as the adult ostriches. They don't have any teeth in their beak so they swallow their food all at once.

Elephants

- African elephants are the largest and heaviest animals on land. They can weigh 6,000 pounds and are very strong.
- Elephants have a trunk. That is a very long nose with which they smell and grasp things. Next to the trunk are the tusks. With the tusks, elephants can fight when they are in danger. They can also push away heavy logs with them.
- Elephants eat all day and even part of the night. They love leaves, branches, grasses, and fruit. The baby elephants still drink their mother's milk.

Crocodiles

- Crocodiles have a long snout and a mouth full of sharp teeth. Their skin is covered with hard bony scales. The scales protect them when they are attacked by other animals.
- The baby crocodiles hatch from eggs that are laid on land. The mother crocodile carries the babies in her mouth towards the water. They can swim immediately.
- Crocodiles like to eat fish and catch animals that drink from the lake. They swim underwater towards the drinking animals and quickly jump out of the water to grab them. The baby crocodiles like to eat frogs, insects, or small fish.

Lions

- Male lions can be recognized by their mane, which is a large amount of hair around the head of the lion. Females do not have mane, they have short hairs all over their body, just like cats do.
- Baby lions are called cubs. Often, four cubs are born at the same time. If a cub has just been born, he can't see anything yet, and he can't walk either. So the female lions have to take care of the cubs very well.
- Lions are mostly asleep during the day, while the cubs play with each other. When it becomes dark, the female lions are going for a hunt. Lions have very good eyesight in the dark. They are predators, so they eat meat. Lion's do not like plants or fruit.

APPENDIX 2B

Questions and scoring of factual knowledge about savannah animals

Question	Answer and scoring	Maximum score
What do ostriches and their young eat?	Grass and fruit, insects and lizards (1 point per correct answer; if children mention both young and adult animals eat grass, still give 1 point)	4
A) What do lions do most of the day? B) And what do they do at night?	A) Sleep (1) The young play with each other (1) B) Hunt (1; If a child mentions that the female lions are the ones hunting, give 0.5 points extra)	3.5
Which animals are family of the zebra?	Horse (1) and donkey (1)	2
A) What do you call a baby lion? B) And how many baby lions are often born at the same time?	A) Cub (1) B) Four (1)	2
What do crocodiles and their young eat?	Fish and other animals/meat. Baby crocodiles eat frogs and insects (1 point per correct answer)	4
What can elephants do with their trunk and their tusks?	A) With the trunk: smelling (1) and grasping things (1) B) With the tusks: fighting (1) and pushing logs/heavy things away (1)	4
What is the difference between a male lion and a female lion?	Male has mane/long hair all around his head, and females do not/females have short hairs (1; if children only mention that males have mane without making a comparison with females, give 0.5 points).	1
How much does an elephant weigh?	6,000 kg (1)	1
A) How are baby crocodiles born? B) And what does the mother do after the baby crocodiles are born?	A) From eggs (1) B) The mother carries her babies in her mouth towards the water (1; If children just say "she brings them to the water", give 0.5 points)	2
Why are ostriches a special kind of birds?	They are the largest/heaviest birds in the world (1); they cannot fly (because they are too heavy; 1); they lay the largest eggs of all birds (1); they can run really fast (1; If children just mention: "they are very big/very heavy/they have strong legs," give 0.5 points)	4
What do zebras and their young eat?	Grasses (1) and leaves (1). The young drink milk from their mother (1)	3
A) What kind of skin does a crocodile have? B) Why is that important?	A) (Hard and bony) scales (1; if children only say: "hard skin," give 0.5 points) B) the scales offer protection (when attacked; 1)	2
What is the difference between a male and a female ostrich?	Males have black feathers and females have brown feathers (1; If children just mention that their feathers have different colors, give 0.5 points) and females are slightly smaller/males are larger (1)	2
A) What are baby zebras able of right after they are born? B) Why is that important?	A) walk (1) and run (1) B) because the foals are able to run away if they are chased by predators/they can escape from predators (1)	3
What do elephants and their young eat?	Leaves, branches, grasses, and fruit. The baby elephants drink their mother's milk (1 point per good answer)	5

(Continues)

[a]*Note* The answers to the questions correspond to the factual knowledge that is offered in the experimental conditions.